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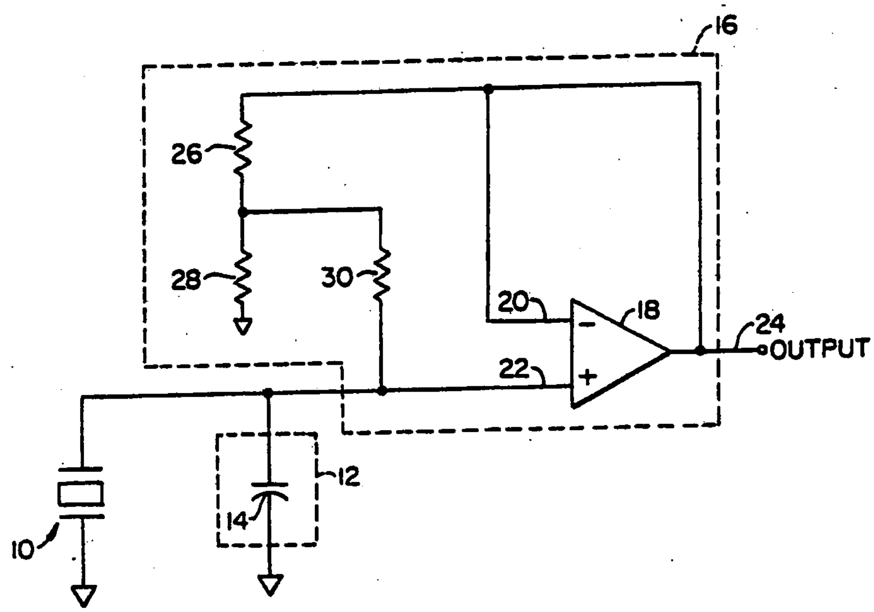
(54) Title: PIEZOELECTRIC POLYMER FORCE TRANSDUCER WITH AN OUTPUT CIRCUIT



(57) Abstract

A transducer system providing extended low frequency response. The system comprises a piezoelectric film transducer (10) which provides a current source type output having low capacity, a capacitor (12) for converting the output of the piezoelectric film transducer (10) into a voltage proportional to the output current of the piezoelectric film transducer (10), and a buffering circuit (16) for providing a predetermined load impedance to the capacitor so as to control the discharge rate of the capacitor and the frequency response of the transducer system.

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Description

PIEZOELECTRIC POLYMER FORCE TRANSDUCER WITH AN OUTPUT CIRCUIT

Technical Field

The present invention is directed, in general, to transducer systems and, more particularly, to a piezoelectric transducer with extended low frequency response.

Background Art

Reference is made to co-pending application entitled PIEZOELECTRIC TRANSDUCER, filed even date herewith.

In the area of biomedical monitoring, transducers which are used to measure respiration are required to have an excellent low frequency response, preferably extending almost to D.C. Where signal sources are used which provide low impedance output signals, little attention is required to be paid to the manner in which the output signals are coupled to the monitoring equipment for processing. However, certain transducer types, such as the piezo film transducer disclosed in the above referenced co-pending application, provide an output signal which has high voltage excursions, but negligible internal capacity. Thus, when conventional amplifying or buffering techniques are utilized with the piezo film transducer, the internal capacity of the piezo transducer discharges too quickly to be used for respiration measurement.

Attempts to raise the standard amplifier input impedance through bootstrap techniques improve the low frequency response of the transducer/amplifier combination by providing an increased load impedance to the transducer. However, there arises an undesirable side effect of increasing the output voltage for a

given transducer displacement. Typically, this output voltage increase is to an unusable level, such that the transducer acts as a current source. In practice, this means that any force supplied to the transducer saturates the transducer amplifier, thus rendering the system unusalbe.

Disclosure Of Invention

The foregoing and other problems of prior transducer system are overcome by the present invention comprising transducer means which provide an output signal in response to force applied thereto, wherein the output signal is in the form of a current having a magnitude proportional to the applied force. Means are provided for converting the current into a voltage which voltage has a magnitude that is proportional to the magnitude of the current. Means are provided which are coupled to the converting means for buffering the output of the converting means and for providing a predetermined low impedance thereto.

In the preferred embodiment of the present invention, the transducer is a piezoelectric film transducer, the converting means comprise a low loss capacitor having a capacitance which is selected as a function of the film area of the piezoelectric transducer, and the converting means is a bootstrap voltage follower which includes an amplifier having negligible input bias current.

With the above structure, the low loss capacitor effectively performs a current-to-voltage conversion of the output signal from the piezoelectric transducer. The capacitance of the capacitor scales the resultant voltage produced by the parallel combination of the capacitor and piezoelectric transducer. The scaling which results is determined by the ratio of the piezoelectric transducer film area to the capacitor

value. In effect, the capacitor accumulates the charge produced by the piezoelectric transducer according to the relationship $V = q/C$ where V equals the voltage on the capacitor, q equals the charge from the piezoelectric transducer, and C equals the capacitance of the capacitor.

The bootstrap amplifier provides a low impedance to the capacitor, which low impedance is selected to control the disc charge rate of the capacitor. By controlling the discharge rate, the desired low frequency response of the transducer/amplifier combination is determinable.

It is, therefore, an object of the present invention to provide a piezoelectric transducer system having an extended low frequency response.

It is another object of the present invention to provide a piezoelectric film transducer which is usable to measure respiration.

It is a further object of the present invention to provide a piezoelectric film transducer and system including a piezoelectric film transducer means for converting the output of the piezoelectric film transducer into a voltage, and buffer means for providing an output which is proportional to the voltage from the conversion means, and which provide a predetermined low impedance to the conversion means.

These and other objectives, features and advantages of the present invention will be more readily understood upon considering the following detailed description of certain prefered embodiments of the present invention and the accompanying drawings.

Brief Description Of The Drawings

Fig. 1 is a schematic of the present invention.

Detailed Description Of The Invention

As discussed above, transducers which provide an output signal that acts as a current source and that has low capacitance are difficult to utilize in monitoring systems. Because of the low capacity of the signal, the low impedances of conventional amplifiers quickly discharge the capacitance and result in very low signal levels. Conversely, where the input impedance of the amplifying circuits used is increased to a higher level, the current source characteristic of the transducer causes the range of transducer output swing to vary between large extremes.

The above difficulties are overcome by the present invention which includes a current-to-voltage converting means, and which provides an amplifier having a predetermined high level input impedance.

Referring to Fig. 1, a piezoelectric transducer 10, such as the piezoelectric film transducer referred to above, is connected in parallel with a current-to-voltage converting means 12. In the prefered embodiment of the present invention, the converting means comprise a capacitor 14. Preferably, this capacitor is a low loss capacitor and has a capacitance value which is related to the piezoelectric transducer film area. Thus, the output voltage produced across capacitor 14 is proportional to the ratio of the piezoelectric transducer film area to the capacitance value. The ratio can be selected to limit the maximum output voltage of the combination.

For example, if a maximum output level of V_{max} were desired for an nominal transducer output of V_{nom}, and transducer internal capacitance of C_{int}, the value

of capacitance would be selected according to the following equation:

$$V_{max} = V_{nom}(C/(C_{int} + C))$$

In Fig. 1, the buffering means 16 are shown, coupled to the piezoelectric film transducer 10 and capacitor 14. The load impedance presented to capacitor 14 by buffeing means 16 is selected so that the discharge rate of capacitor 14 is compatible with the frequency of the motion which is to be monitored. Thus, where very low frequency motions or movements are sought to be monitored, the discharge rate will be selected to the 10 or 100 times lower than the rate being monitored.

Referring more specifically to buffering means 16, it can be seen that said means 16 comprise a differential amplifier connected in a bootstrap/voltage follower mode.

Differential amplifier 18 has an inverting input 20, a non-inverting input 22, and an output 24. The output 24 of differential amplifier 18 is connected to the inverting input 20 thereof. The non-inverting input 22 is connected to the junction of capacitor 14 and piezoelectric film transducer 10.

In order to form the bootstrap feature of buffering means 16, a first resistance 26 is connected at one end to the inverting input 20 of differential amplifier 18. One end of a second resistor 28 is connected to the other end of resistor 26. The other end of resistor 28 is connected to ground or the reference point for the circuit. A third resistor is connected at one end to a non-inverting input 22 of the differential amplifier 18 and at the other end to the junction of first and second resistors 26 and 28, respectively.

It can be shown that where differential amplifier 18 is an ideal amplifier, the load impedance presented by buffering means 16 is substantially equal to the ratio of the value of the second resistor 28 to the value of first resistor 26 multiplied by the value of third resistor 30.

Where the input bias current of inverting input 20 and non-inverting input 22 of differential amplifier 18 are negligible, the current flowing through third resistor 30 is determined by the voltage across first resistor 26. This is because, for an ideal amplifier, the voltage difference between its inverting and non-inverting input is 0.

The voltage across first resistor 26 is determined by the voltage divider relationship of first resistor 26 and second resistor 28 applied to the output voltage level. Because the differential amplifier 18 is connected in a voltage follower mode, the output voltage level at output 24 is substantially equal to the input voltage level present at non-inverting input 22.

Given that impedance is defined by the voltage divided by current, the load impedance presented by buffering means 16 is defined by the voltage across capacitor 14 divided by the current into buffering means 16. When differential amplifier 18 is an ideal amplifier, i.e., the current into non-inverting input 22 is substantially 0, substantially all of the current flowing into buffering device 16 from capacitor 14 flows through resistor 30.

As discussed above, the current through third resistor 30 is determined by the voltage across first resistor 26. The voltage across first resistor 26 is substantially equal to the voltage at output 24 multiplied by the value of first resistor 26 divided by the sum of the value of first resistor 26 and second

resistor 28. The current then flowing through the third resistor 30 is determined by the voltage across first resistor 26 divided by the value of third resistor 30. The load impedance presented by buffering means 16 is then the voltage across capacitor 14 divided by the current through third resistor 30.

For example, if the output voltage of differential amplifier 18 is one volt and the ratio of second resistor 28 to first resistor 26 is 100, then only one 100th of a volt, or 10 millivolts, will be applied across third resistor 30. If only one 100th of the voltage is applied, then the effective value of third resistor 30 is multiplied by the ratio of the second resistor 28 to the first resistor 26. Where first resistor 26 has a value of 100 ohms and second resistor 28 has a value of 10,000 ohms, and where third resistor 30 has a value of 22 megohms, the effective value of third resistor 30 is substantially 2,200 megohms.

For the values discussed in the example above, buffering means 16 have been found to be satisfactory when used with a capacitance for capacitor 14 of .1 microfarads and a piezoelectric film transducer film area of 1 and 1/4 square inches.

Preferably, the input bias current of differential amplifier 18 is negligible. That is, the maximum bias current of the differential amplifier used should be low enough to allow the bootstrapped high impedance described above to control the discharge rate and the low frequency response characteristics of the transducer system. In the example described above, ampliers with subpicoampere (i.e. less that one picoamp) bias currents, such as the AD 515 series manufacrured by Analog Devices, Inc. of Santa Clara, California, have been found to be satisfactory. This series of devices provide approximately 75 femto amps of input bias current.

The terms and expressions which have been employed here are used as terms of description and not of limitations, and there is no intention, in the use of such terms and expressions of excluding equivalents of the features shown and described, or portions thereof, it being recognized that various modifications are possible within the scope of the invention claimed.

WHAT IS CLAIMED IS:

1. An apparatus for converting force into and electrical signal comprising

a transducer which provides an output signal in response to the force wherein the output signal is in the form of a current having a magnitude proportional to the force being applied;

means for converting the current into a voltage having a magnitude which is proportional to the magnitude of the current; and

means coupled to the converting means for buffering the output of the converting means and for providing a predetermined load impedance thereto.

2. The apparatus of claim 1 wherein the transducer comprise a piezoelectric film transducer and further wherein the output signal from the piezoelectric transducer comprises a quantity of electric charge which is proportional to the force being applied thereto, and further wherein the converting means include for storing the electric charge, the storing means providing a signal having an output voltage magnitude which is proportional to the magnitude of the stored charge.

3. The apparatus of claim 2 wherein the storing means have a predetermined capacitance.

4. The apparatus of claim 3 wherein the storing means comprise a capacitor.

5. The apparatus of claim 4 wherein the capacitor is a low loss capacitor.

6. The apparatus of claim 1 wherein the buffering means comprise means for amplifying the output of the converting means said amplifying means having a substantial input impedance.

7. The apparatus of claim 5 wherein the buffering means include an amplifier having a bootstrapped input section.

8. The apparatus of claim 7 wherein the amplifier is a voltage follower.

9. The apparatus of claim 7 wherein the output voltage magnitude and the output of the converting means are measured relative to a reference point and further wherein the bootstrapped input amplifier comprises

a differential amplifier having an inverting input, a non-inverting input and an output wherein its output is connected to the inverting input and the non-inverting input being coupled to the converting means;

first means connected between the inverting input of the differential amplifier and the reference point for providing a predetermined amount of impedance wherein the first means include an intermediate node and further wherein substantially all of the predetermined impedance is provided between a first end of the first means and the intermediate node; and

second means connected at one end to the non-inverting input of the differential amplifier and at the other end to the intermediate node of the first means for providing a predetermined amount of impedance so that substantially all of the predetermined amount of impedance provided by the first means are connected between the other end of the second means and the reference point, and so that the remainder of the predetermined amount of impedance provided by the first means are connected between the inverting input of the differential amplifier and the other end of the second means;

wherein a load impedance is provided to the converting means which has a magnitude determined by the magnitude of the predetermined amount of impedance provided by the second means multiplied

by the ratio of the amount of impedance provided by the first means between the intermediate node and the reference point to the amount of impedance provided by the first means between the intermediate node and the inverting input of the the differential amplifier.

10. The apparatus of claim 9 wherein the first and second means provide predetermined amounts of resistance.

11. The apparatus of claim 10 wherein the predetermined amount of resistance provided by the second means is at least one megohm, and further wherein the ratio of the resistances between the ends and intermediate node provided by the first means is at least 100:1.

12. The apparatus of claim 11 wherein the second means provides approximately 22 megohm of resistance and the first means provide approximately 100 ohms of resistance between the intermediate node and the inverting input of the differential amplifier, and approximately 10,000 ohms of resistance between the intermediate node and the reference point.

13. The apparatus of claim 6 wherein the amplifying means has an input bias current of less than one picoamp.

14. The apparatus of claim 13 wherein the amplifying means has an input bias current of approximately 75 femtoamps.

15. The apparatus of claim 3 wherein the piezoelectric film transducer has a predetermined film area and further wherein the proportionality of the voltage provided by the converting means is a function of the ratio of the film area to the amount of capacitance provided by the converting means.

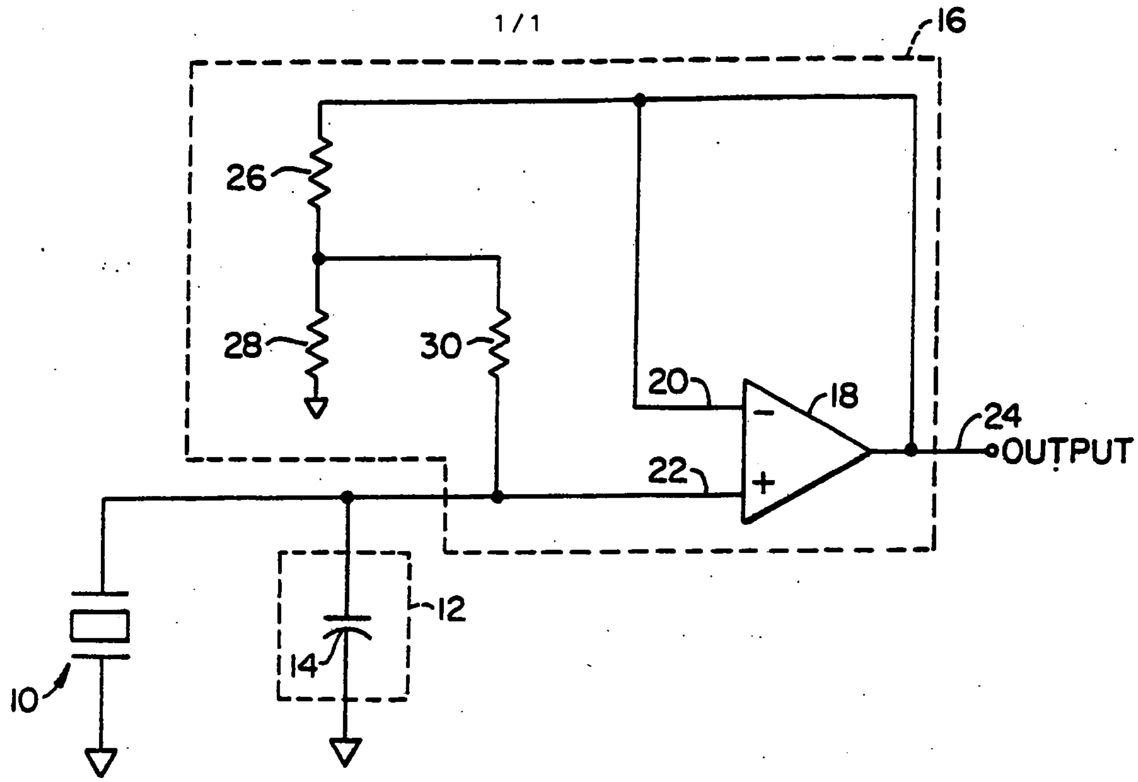

FIG. 1.

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INTERNATIONAL SEARCH REPORT

International Application No PCT/US85/00906

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL.^{3} H01L 41/08
US. CL. 310/319

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	310/316, 319, 329, 800

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X	US, A, 4,085,349, Published 18 APRIL 1978 J. T. FARSTAD	1
Y	US, A, 4,328,441, Published 04 MAY 1982 F.R. KROEGER et.al.	2-15
A	US, A, 3,900,830 Published 19 AUGUST 1975 H.O. PETERSON	1-15
A	US, A, 3,389,276, Published 18 JUNE 1968 J.H. GRADIN. et. al.	1-15
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IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
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